EFFECTS OF GEOLOGIC AND HYDROLOGIC FACTORS AND WATERSHED CHANGE ON AQUATIC HABITAT IN THE YAKIMA RIVER BASIN, WASHINGTON

Tom Ring,[1] And Bruce Watson,[2]

INTRODUCTION

The Yakima River drains the eastern slope of the Cascade Range in central Washington and flows through 150 miles of semi-arid lowland valleys and canyons before joining the Columbia River. This paper discusses the geology, hydrology, and fluvial geomorphology that formed the physical template for an abundant cold-water aquatic ecosystem under pre-development conditions and changes in the watershed that have altered these processes. A new analytical tool is described that uses these geological underpinnings to evaluate habitat alterations for anadromous salmonids.

Anadromous fish runs are currently about 1% of historical run sizes. Under pre-development conditions, alluvial flood plains with complex multiple channels and underlying alluvial aquifers damped snowmelt-driven runoff, sustaining favorable conditions of flow, temperature, and food web production through the hot, dry summer. Hydrograph alteration, river/floodplain disconnection, channel network simplification, etc., have impaired ecosystem function and reduced fish production dramatically. The paper describes techniques for estimating the influence of these changes on production and survival of anadromous fish.

PHYSICAL SETTING

Patterns of streamflow and water quality in the Yakima basin are shaped by the distribution of precipitation and geology. Vulcanism, uplift, folding and faulting, glaciation, and gravel deposition created numerous alluvial valleys separated by short bedrock canyon reaches. In the semi-arid lowlands, these geologic controls, along with the temporal and spatial distribution of surface water delivered from the upper watershed, determine the timing and location of most groundwater recharge and discharge, and the mechanism by which streamflow and water temperature are moderated.

Yakima River basin geology and hydrogeology fall in two main regions: a Cascade Mountains province in the northwestern Yakima basin with a varied suite of older rocks; and the Columbia Plateau province, where a thick sequence of basaltic lava flows and overlying sediments cover the older rocks. The basalt plateau of the eastern basin was folded and faulted into northwest-southeast trending anticlinal ridges and synclinal valleys called the Yakima Fold Belt. The antecedent Yakima River incised canyons and water gaps through the ridges and deposited gravels eroded from uplifting mountains and ridges in the valleys.

Alpine glaciers draining the Cascade crest delivered large volumes of gravel to the alluvial basins. Glaciation left many lakes, four of which were expanded to serve as storage reservoirs. Backwaters from the ice-age Lake Missoula flood left thick silt deposits in the lower valley.

The Columbia River Basalts, interbeds, and overlying sediments form a regionally important aquifer

[1] **Hyrdogeologist, Yakama Nation Water Program, P.O. Box 151, Toppenish, WA, 98948 (509) 865-5121 ext 660, fax (509) 865-1925, e-mail ringt@yakama.com.**

[2] **Planner, Yakima Klickitat Fisheries Project, 771 Pence Rd., Yakima, WA, 98902 (509) 966-5156, fax (509) 966-7406, e-mail yinykfp@wolfenet.com.**

system. The alluvial aquifers are generally quite permeable, but heterogeneous and anisotropic due to deposition in dynamic fluvial environments. Cascade Mountains province rocks store and transmit little water.

Orographic uplift and cooling of moist air from the Pacific Ocean cause high precipitation along the Cascade crest (Pacific Northwest River Basins Commission, 1970). Warming and drying of the descending air mass east of the crest causes a strong rain shadow effect (120 in/yr precipitation on the crest, <10 in/yr in most of the lower basin). Runoff and precipitation-induced groundwater recharge are low in the lower basin; 75% of precipitation comes from October through March, much of it snowfall along the crest. Snowpack builds from October through April. A dry season runs from late spring through summer, with less than 5% of precipitation occurring in July and August. High elevation snowpack remains until June or later, causing runoff to persist well into summer. Estimates of the unregulated hydrograph in the lower basin show annual peaks in April through June in the range of 7 to 12 kcfs, with annual lows in September or October of about 1,000 cfs (Parker and Storey, 1916). Record peaks, however, are rain-on-snow events occurring between November and February.

Geologic structure strongly influences patterns of streamflow, natural storage and baseflow, and surface-ground water interactions. Runoff predominates on the steep bedrock crags of the Cascades. Floodplains damp the snowmelt-generated hydrograph, store peaks and releasing baseflows. Lake and ground storage were the major sources of pre-development late summer flow (Parker and Storey, 1916; Kinnison and Sceva, 1963).

PRE-DEVELOPMENT WATERSHED CONDITIONS AND ECOSYSTEM FUNCTIONS

Reaches associated with alluvial flood plains have been shown to be centers of biological productivity and ecological diversity in gravel bed rivers (Stanford and Ward, 1988; Independent Scientific Group, 1996). In the Yakima basin, bedrock constrictions between alluvial subbasins control the exchange of water between streams and the aquifer system. Under pre-development conditions, vast alluvial flood plains were connected to complex webs of braids and distributary channels . These large hydrological buffers spread and diminished peak flows, promoting infiltration of cold water into the underlying gravels. Side channels and sloughs provided a large area of edge habitat and a variety of thermal and velocity regimes. For salmon and steelhead, these side channel complexes increased productivity, carrying capacity and life history diversity by providing suitable habitat for all freshwater life stages in close physical proximity. The hyporheic zone (zone of shallow groundwater made up of downwelling surface water) extended the functional width of the alluviual flood plain and hosted a microbe- and invertebrate-based food web that augmented the food base of the ecosystem. As snowmelt-generated runoff receded through the summer, cool groundwater discharge made up an increasing proportion of streamflow. Much of this groundwater upwelled from the gravel into complex channel networks upstream of bedrock constrictions.

Temperature is a key environmental variable for salmonids and other stenotherms. River/floodplain interactions provided cool, clear base flows during times of low flow and high air temperatures, creating thermal refugia for outmigrating smolts and returning adults moving through the hot lower basin. In winter, upwelling groundwater prevented freezing and drove the flow of oxygenated water through the gravel substrate, providing excellent conditions for incubating eggs and alevin.

WATERSHED CHANGE, CURRENT CONDITIONS, AND IMPLICATIONS FOR FISH PRODUCTION AND SURVIVAL

Flood plain isolation and channel simplification, combined with inversion and truncation of the natural hydrograph, have dramatically reduced river-flood plain interactions and degraded the aquatic environment.   The flood plain is isolated by diking, channelization, wetland draining, gravel mining, and highway and railroad building, and many of these same activities eliminated or isolated vast areas of side channels and sloughs. River regulation for irrigation and flood control alter the natural hydrograph by impounding spring freshets, substantially increasing summer flow, and decreasing winter flow. A common effect of these developments is a sharp reduction in the frequency with which the alluvial flood plain aquifer system is recharged by spring floods. Water temperatures in the lower river are therefore higher in the summer, and the number and extent of thermal refugia are reduced.

Comparison of current observed flows and estimated unregulated hydrographs show pronounced hydrologic change. Capture of freshet in reservoirs decreases frequency and duration of overbank flows. Irrigation diversions partially or totally dewater downstream reaches, while delivering stored irrigation water to downstream diversion points through the river channel causes unnaturally high flows in others. Irrigation has increased aquifer recharge but has also delayed it, increasing the mean temperature of infiltrating water. In the upper mainstem Yakima, where most reservoir storage is located, the spring freshet is captured and then released in mid-summer to satisfy downstream irrigation demand. The Naches arm retains a more natural hydrograph due to large unregulated tributaries, but here also an unnatural fall spike is caused by "flip-flop" -- an annual shift of irrigation releases from the upper Yakima to the Naches arm intended to prevent dewatering of upper Yakima salmon redds during reservoir refilling in the late-fall and winter . In the lower river (mainstem below Sunnyside Dam), a diminished spring freshet still occurs, but low flow conditions are reached early in summer, and the entire hydrograph is well below natural.

Physical alterations including diking, roads, and railroads have reduced access to the flood plain and have destabilized or armored the streambed. Side channel habitat has been blocked or eliminated. The river has been channelized and simplified, and thus provides less reach-scale spatial diversity with respect to temperature and velocity. Riparian flood plain gravel mining has removed surface and subsurface habitats; cool inflow to pit ponds is heated and returned to the river.

These processes have reduced or reversed natural thermal moderation by flood plain reaches. The river is hotter in summer, and thermal refugia are fewer and hotter.

ECOSYSTEM DIAGNOSIS AND TREATMENT

Ecosystem Diagnosis and Treatment (EDT) is a quantitative analytical tool for estimating production potential of a basin for anadromous salmonids (Lichatowich et al 1995; Lestelle et al 1996; Mobrand et al 1997; Mobrand et al 1998). This analytical approach has been formulated into a computer model, being used by the Yakama Nation to guide planning and evaluation of future and ongoing supplementation projects, land use activities, and habitat restoration measures in the Yakima basin (Mobrand Biometrics 1999).

EDT is a watershed approach to quantifying suitability of a river system for salmon and steelhead production. Broadly, EDT calculates the suitability of the existing, degraded ecosystem (the "Patient") and the healthy, pre-development system (the "Template") by evaluating 14 "environmental attributes" critical to the survival of salmonids, and by estimating the amount of "key habitat" available. The contrast between Patient and Template in terms of productivity and carrying capacity and, especially, the environmental factors causing this contrast, represents the ecological "diagnosis" of the Patient, and focuses future rehabilitation projects.

"Environmental attributes" consist of such measures as "percent fines in substrate", "mean monthly water temperature", "habitat complexity" (number and distribution of side channels, pieces of large woody debris, etc.) and "appropriate flow" (magnitude, variability, etc). The quality of each attribute is expressed as a fraction of the optimal value for a specific life stage of a specific species, and is assumed to represent a fractional decrease in survival probability due to a specific attribute. The product of all attribute-specific relative survival values and maximum reported survival rate for the life stage is assumed to represent the actual survival for a particular life stage in a particular reach. "Key habitat" consists of the area of a reach optimal for a specific life stage (e.g., shallow, low velocity pools for fry).

This qualitative and quantitative analysis occurs in the context of two spatiotemporal "landscapes", a survival landscape and a capacity landscape. Conceptually, these landscapes are a matrix in which columns represent time, and the life stages expected at a given time; and rows represent successive reaches and tributaries in a river basin. A productivity value and carrying-capacity value is associated with each reach-by-week cell in each landscape. Importantly, environmental attributes and key habitat are evaluated for every life stage in every cell of both landscapes.

Using life-stage-specific movement patterns, the EDT model then "draws" all biologically plausible trajectories through the landscapes, starting with adults entering the Yakima and ending with smolt progeny entering the Columbia. The model then estimates productivity and carrying capacity for any single trajectory (life history type), for any collection of trajectories, or for the basin as a whole.

The importance of contrasting Template with Patient cannot be overstressed. Often, and certainly in the Yakima, the structure and function of the historical ecosystem bears virtually no resemblance to the current ecosystem. Therefore, despite difficulties in doing so, the Template must be painstakingly reconstructed, because it represents the idiosyncratic "formula for success".

In many cases, critical habitats were altered or destroyed before being adequately characterized. The value and function of these watershed components must be reconstructed using a variety of evidence and methods including: historic mapping and aerial photographs; analogy to similar, intact habitats; knowledge of the habitat requirements of native species; professional judgement; and first principles of hydrology and hydrogeology. EDT uses these comparisons of Patient and Template conditions to estimate productivity, carrying capacity and equilibrium abundance for observed and hypothetical conditions and thus allows quantitative evaluation of alternative enhancement proposals. This paper focuses on changes between current and reconstructed natural hydrologic and hydrogeologic conditions in the Yakima basin, how those changes affect the anadromous fish production and, with the assistance of EDT analysis, the kinds and magnitudes of changes that must occur for varying degrees of restoration of historical fish production.

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